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DEVELOPMENT OF A NOVEL HIGH VELOCITY OIL SLICK SKIMMER

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Hydronautics, Incorporated

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16. Abstract

Experimental investigations show that thin slicks of oil can be recovered in currents of up to 10 fps with a new Surface Velocity Retarder Oil Skimmer (SVROS). This collection device is composed of an array of closely spaced flat plates. The plates serve to gradually dissipate the kinetic energy of the oil/water inflow so that oil can be collected at high relative velocities without the entrainment losses typical of all simple oil booms in currents over about one knot. Tests, in prototype scale, were performed on a thin model of the device. Test variables included velocity, plate spacing and depth, oil type, and slick thickness. The test results are presented with conclusions and recommendations for further development.

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PREFACE

The author wishes to acknowledge the contributions of Mr. Clinton E. Brown and Dr. Arye Gollan to this project. Mr. Brown is the principal inventor of the SVROS concept. Dr. Gollan directed the fabrication of the model and most of the model tests. LCDR Donald Jensen acted as project officer for the United States Coast Guard.

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INTRODUCTION

Laboratory experiments[1] and field experience[2] have shown that conventional oil booms fail to contain oil effectively in relative currents exceeding a critical velocity of about one knot. This critical velocity is relatively independent of oil type, but depends largely upon the balance of forces at the oil/water interface, i.e., the ratio of the dynamic or inertial forces to the interfacial surface tension forces. When the shear stresses at the interface are sufficiently large, droplets of oil are formed which are then entrained into the underlying water phase and flow beneath the oil boom.

Analysis of the problem[3] indicates that a critical speed is associated with the formation of droplets at an oil/water interface. Actually it is the relative velocity between the oil and water layers that is instrumental to droplet formation. The critical velocity is proportional to the product of interfacial tension and difference in densities to the one-fourth power and, hence, does not vary significantly for most oil products. Experiments have, in fact, shown that the critical speed lies close to one foot per second; any increase in relative velocity results in a marked increase in the volume rate of droplet production and a decrease in droplet size.

These considerations lead to very important conclusions: any device meant to contain oil slicks in a fast current must accomplish a gradual and simultaneous slowing down of both the oil and the water layer immediately below it in such a manner that the relative velocity between the oil and water does not exceed about one foot per second. A second and equally important consideration is that the device must accomplish the above without creating a significant upstream influence. That is, it must not create a "blockage" to the flow lest it have the same

effect as a simple boom at high speeds with the oil being heavily entrained in the flow ahead of the device.

The basic objective of the Surface Velocity Retarder Oil Skimmer (SVROS)* is to gradually dissipate the kinetic energy of a thin incoming oil slick and a moderate layer of the underlying water so as to prevent droplet entrainment in currents greatly exceeding one knot. At the same time, the slick thickness is greatly increased within the device to permit efficient oil withdrawal. The SVROS is simply a collection device composed of closely-spaced flat plates arranged vertically and parallel to the flow. Viscous eddy dissipation serves to gradually transfer energy between the skimmer and the upper surface layers of the flow. The plates are open on the bottom to allow the necessary expansion of the fluid streamlines without creating a blockage to the flow.

The development program reported herein was undertaken to demonstrate the feasibility of the SVROS concept and to determine its operating characteristics and capabilities for skimming thin oil slicks in currents up to 6 knots. The work included: construction of a 9 foot long SVROS model, modifications to an existing 80 foot long towing tank carriage and drive system to enable towing speeds up to 6 knots, and a test program featuring thin oil slicks of both No. 2 Fuel Oil and 30 Wt motor oil.

*Note: The SVROS concept is proprietary to HYDRONAUTICS, Inc. and patent application has been made.

TEST APPARATUS AND PROCEDURES

The SVROS Model

A thin spanwise section of a full scale SVROS was fabricated of aluminum plates and spacers. The 1/32-in. baffle plates are 90 inches long and spaced either 1/4-in. apart or 17/32-in. apart (by removing every other plate). The total width of the module between the sidewalls is 3-29/32-in. The overall length is 9 feet. The sidewalls were extended forward of the baffles to promote two-dimensional flow into the model. The after extension of the sidewalls houses a removable oil collection box. A sketch and photograph of the model are shown respectively in Figures 1 and 2.

One sidewall was made of 3/8-in. clear acrylic to enable the first oil collecting channel to be viewed from the side. The leading edge of this wall was made sharp by chamfering the outside corner of the plate.

The 1/4-in. spacers along the top of the model have 2-in. slots (as shown in the sketch) to allow velocity measuring (pitot) probes to be inserted in any channel at four longitudinal stations. The plate spacing along the baseline and at mid-depth was maintained by means of 0.06-in. threaded rods through the model at some fourteen locations (not shown).

The oil collecting box is made of clear acrylic plates. The front side and bottom have several rows of 5/16-in. holes to allow flow of oil and/or water into or through the box. The holes can be closed with rubber stoppers, or the box simply turned around, to prevent flow in the box, as desired.

The 80-Foot Towing Tank

The SVROS model was tested in an 80-foot long towing tank shown in Figure 3. The tank cross section is 2-ft by 2-ft. One

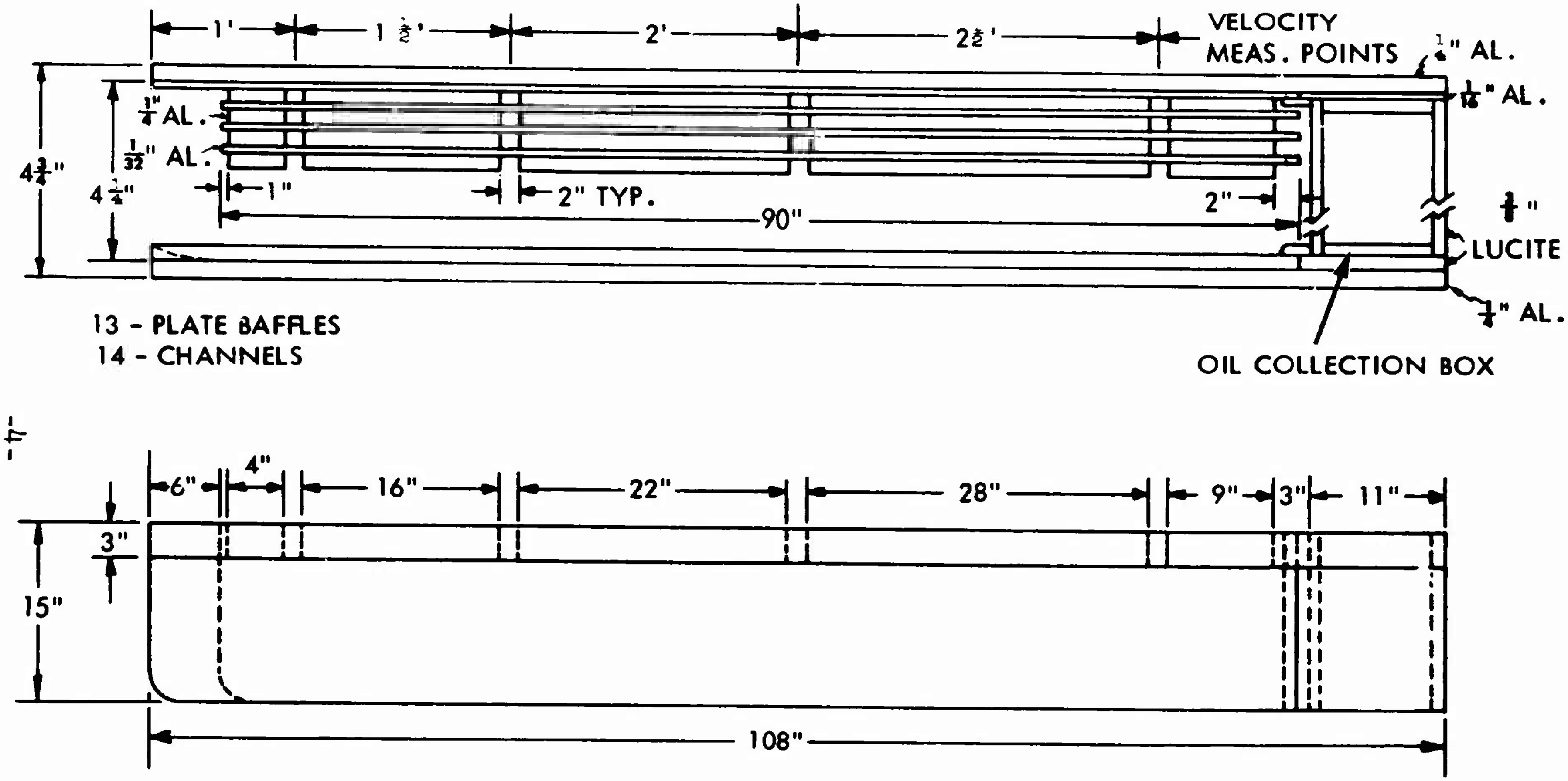


FIGURE 1 - SKETCH OF SVROS MODEL (NOT TO SCALE)

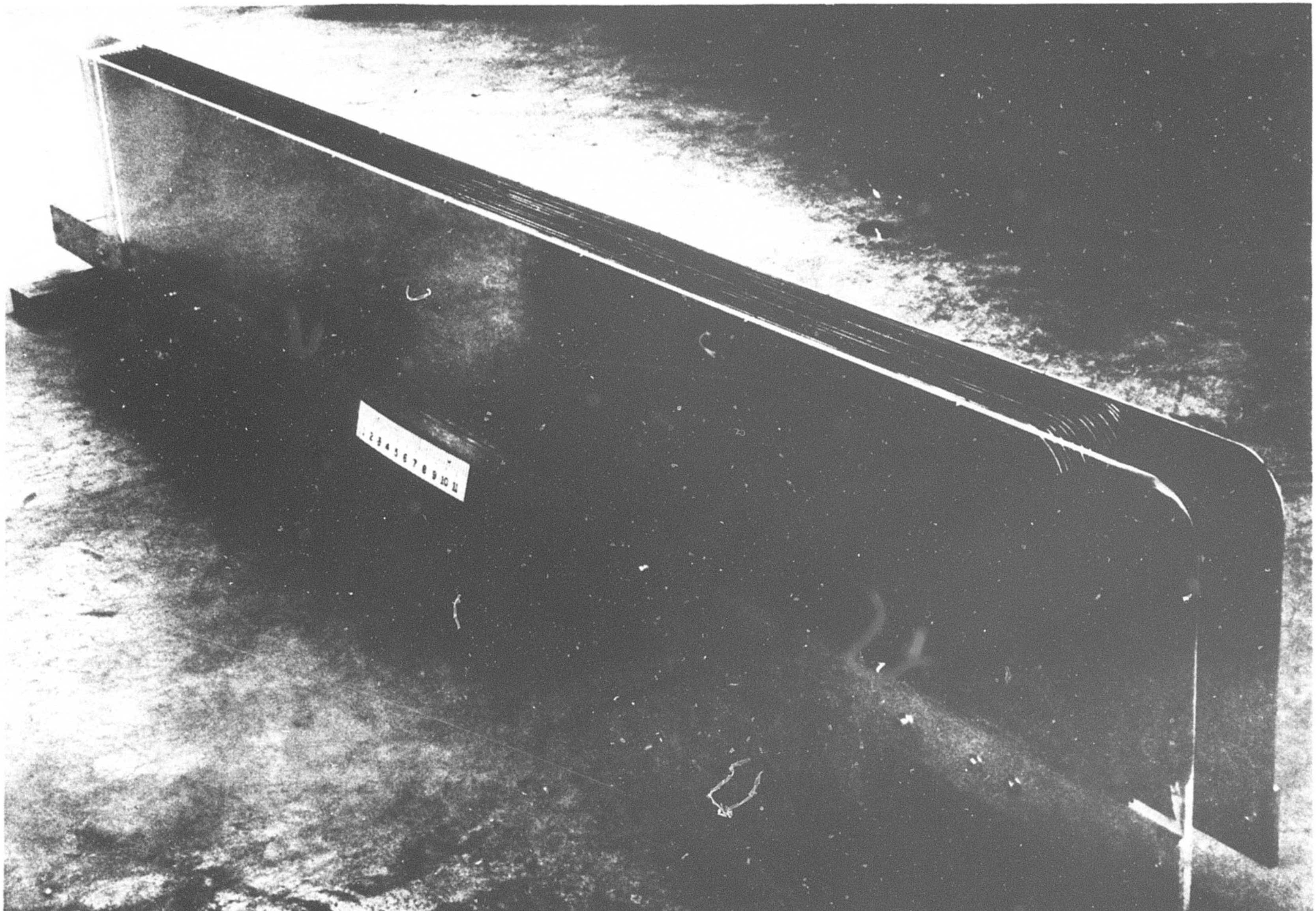


FIGURE 2 - VIEW OF SURFACE VELOCITY RETARDER OIL SKIMMER (SVROS)
(Note: Model is upside down)

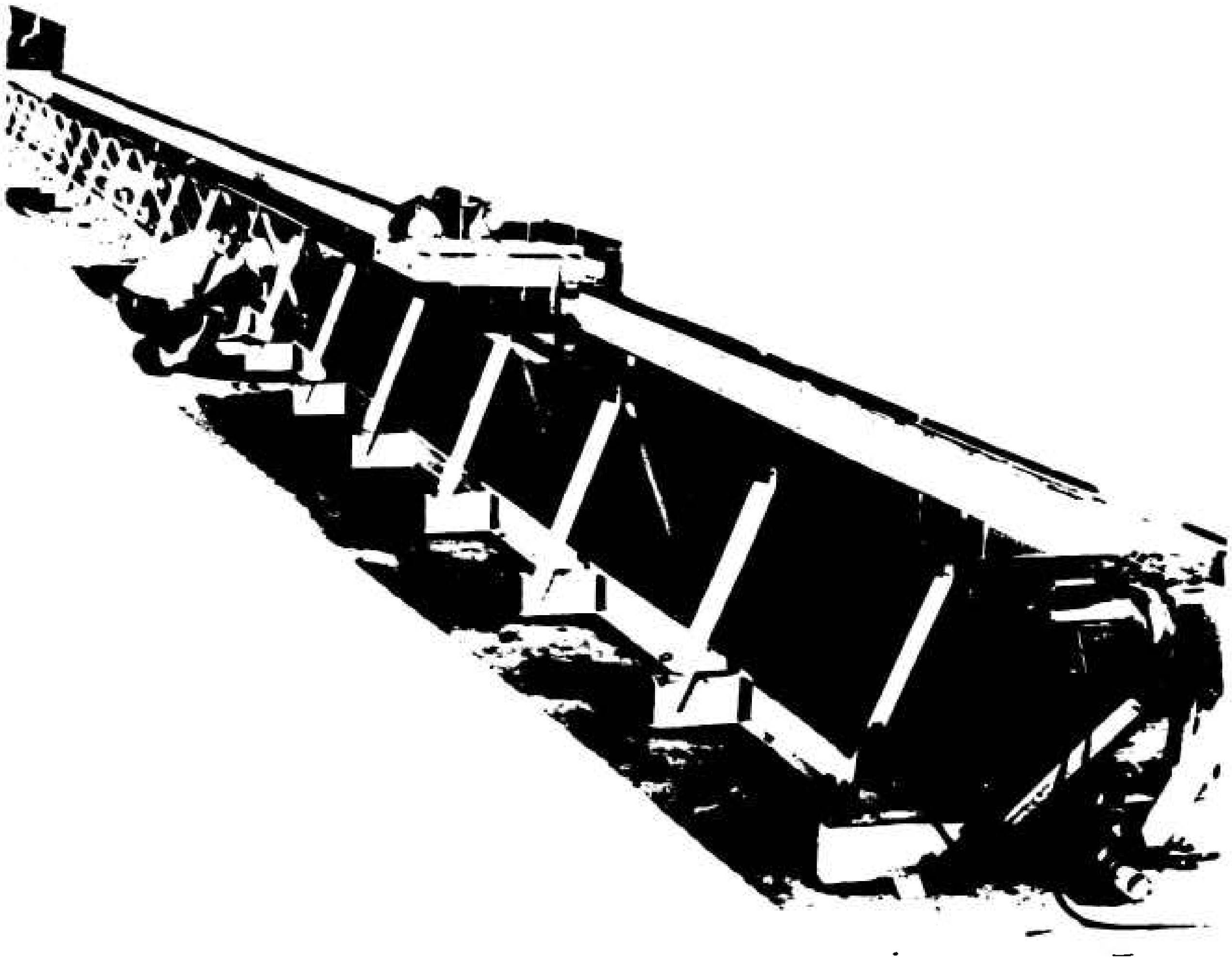


FIGURE 3 - VIEW OF THE 80'-LONG TOWING TANK

side is clear acrylic which allows observations and photographs to be made. Several modifications to the tank's carriage and drive system were required to support this model and tow it at speeds up to 10 fps. A new aluminum carriage was constructed and a new 2 HP variable speed motor drive was installed. The motor drives the carriage through a continuous cable system. Views of the carriage and drive system are shown in Figure 4.

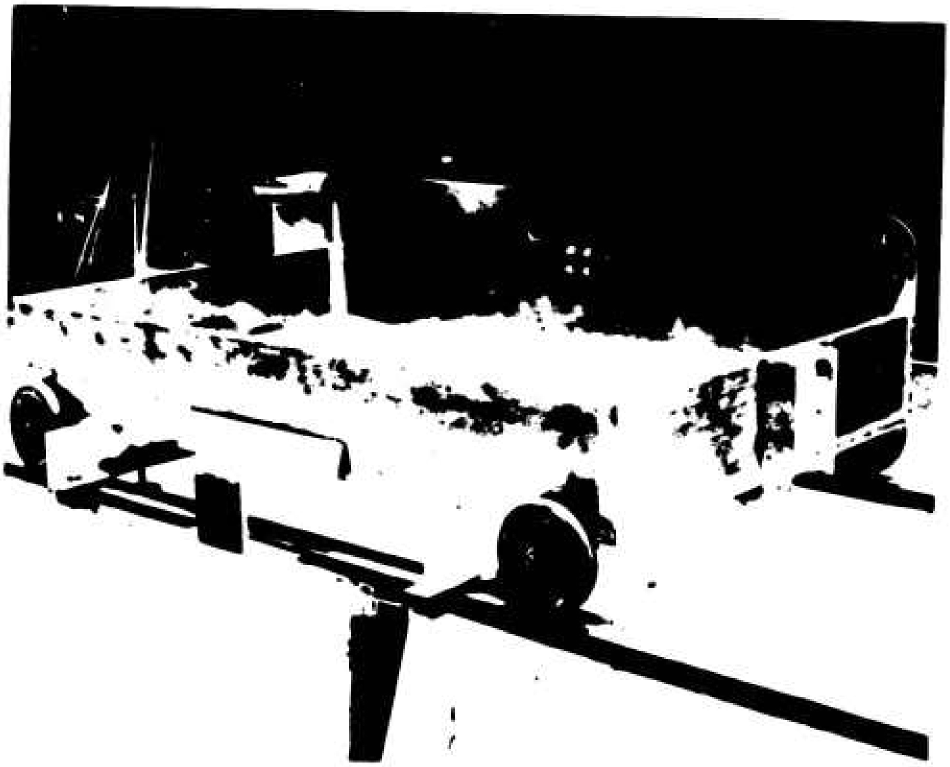
In order to increase the operational safety of the towing carriage at high speeds, a series of electrical limit switches were incorporated in the motor control system. In addition, two shock absorbers were installed at the far end of the channel as a final safety measure.

The carriage velocity was calibrated with respect to a dial setting on the variable-speed-drive motor. A modification to the motor control caused a change in calibration half-way through the test program. Both calibrations are shown in Figure 5. A third digit (0) was arbitrarily added to the dial settings for the second calibration.

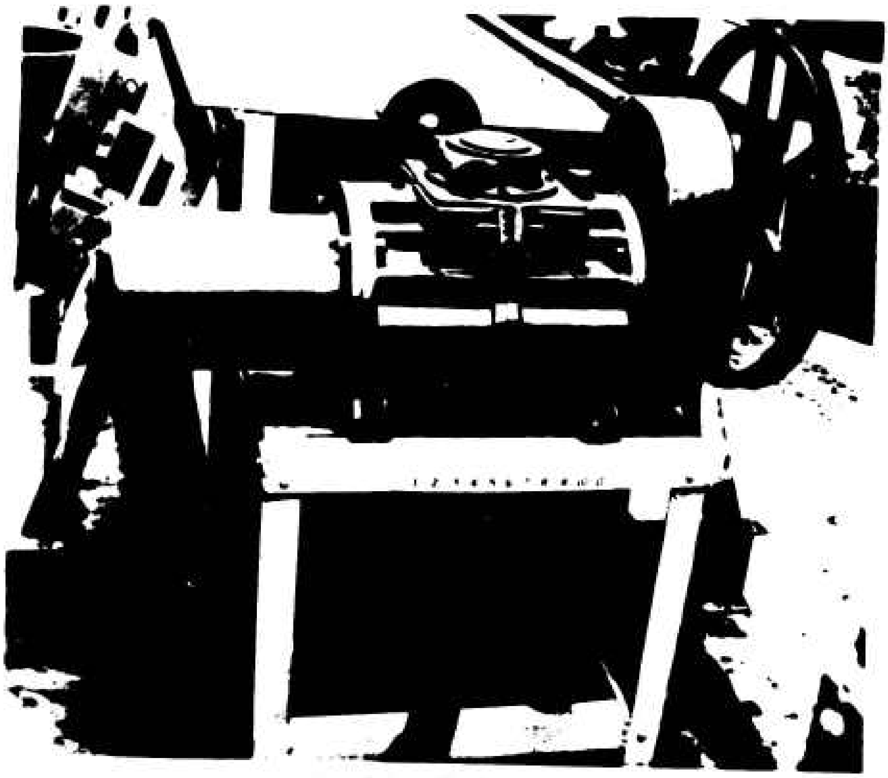
Velocity Field Measurements

Eight manometers measured the total head sensed by small (1/16" diameter) pitot probes placed in the SVROS channels at four stations. The two probes at each station were at different depths below the undisturbed free surface. A different channel was sampled by each pair of probes so that the flow at the downstream stations was not disturbed by the probes at upstream stations.

The upper ends of the manometer tubes were manifolded to a vacuum chamber. Thus, the water level in the manometers was raised above the carriage to allow an unobstructed view at all



a. Carriage



b. Drive System

FIGURE 4 - VIEWS OF THE CARRIAGE AND DRIVE SYSTEM

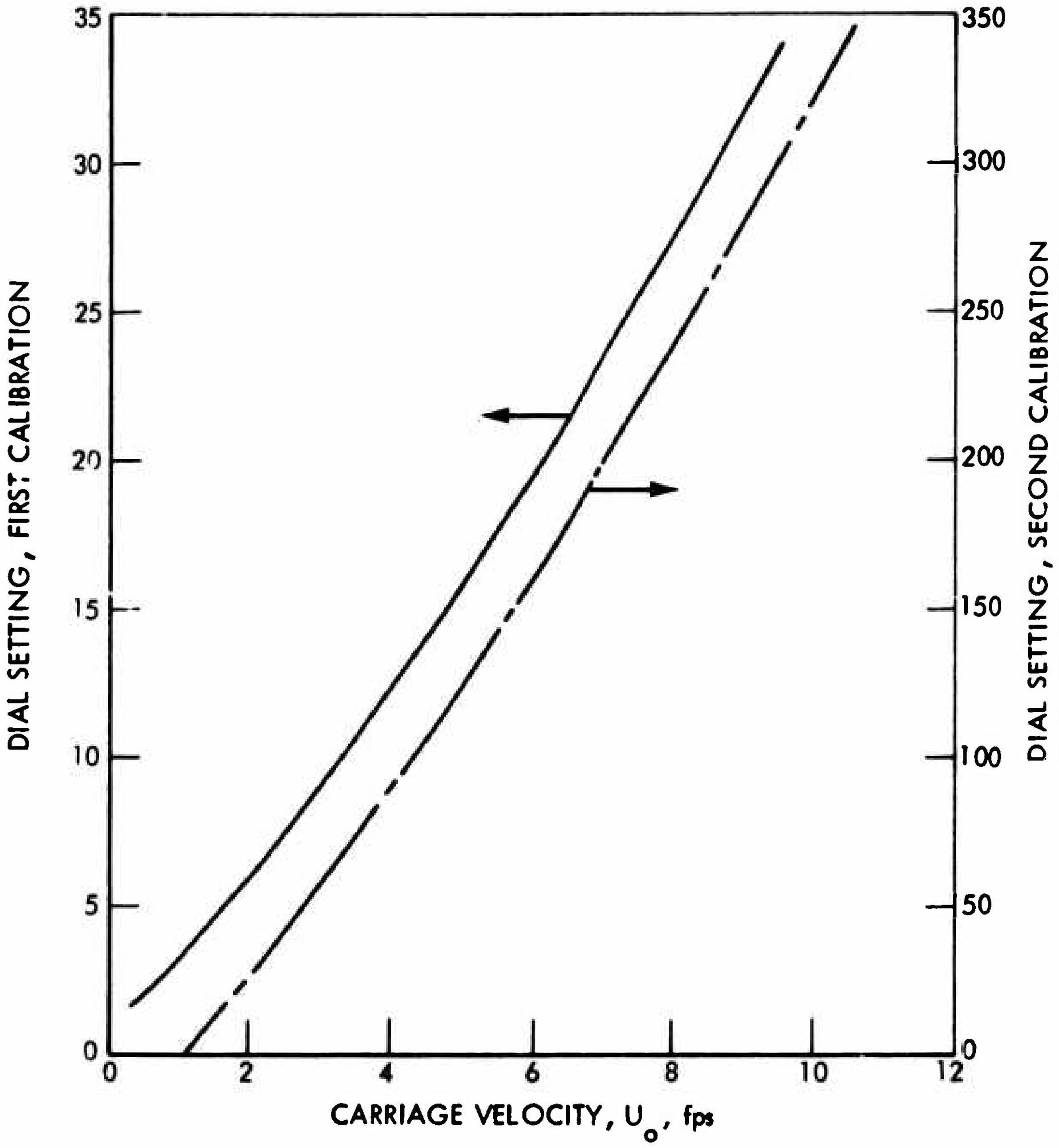


FIGURE 5 - CARRIAGE VELOCITY CALIBRATION

times. A vertical scale was placed between each pair of manometer tubes for convenience in reading the total head, the difference in manometer levels while at rest and while underway.

Manometer readings were taken in real time by observers moving with the carriage. It was noted that the levels were somewhat unsteady. The observers attempted to read the mean levels. At higher velocities, real-time observations became difficult to make. Photographs were taken as the model passed by a station near the middle of the towing tank. These photographs were viewed later to obtain instantaneous manometer readings (and free surface profiles).

Carriage velocity and model immersion depth were the major test variables. Immersion depth was controlled by raising and lowering the water depth in the tank. The model baseline was 10-in. above the tank bottom. In one test series only the lateral position of the pitot probes was changed, i.e., different channels were sampled for comparison.

A few runs were made in which dye was ejected into the first channel to obtain visual traces of the flow streamlines. The dye was rapidly dispersed by the turbulent flow , however, and this technique was abandoned.

Oil Skimming Tests

Skimming tests were conducted with two oils: No. 2 Fuel Oil and SAE 30 wt. motor oil. Their viscosities were determined as a function of temperature as shown in Figure 6. Their specific gravities are nominally 0.83 and 0.89, respectively.

Oil Preload Tests - Two types of tests were made with oil: preload and thin slick. In oil preload tests, a small quantity of oil was trapped in the outside channel by means of a foam rubber dam

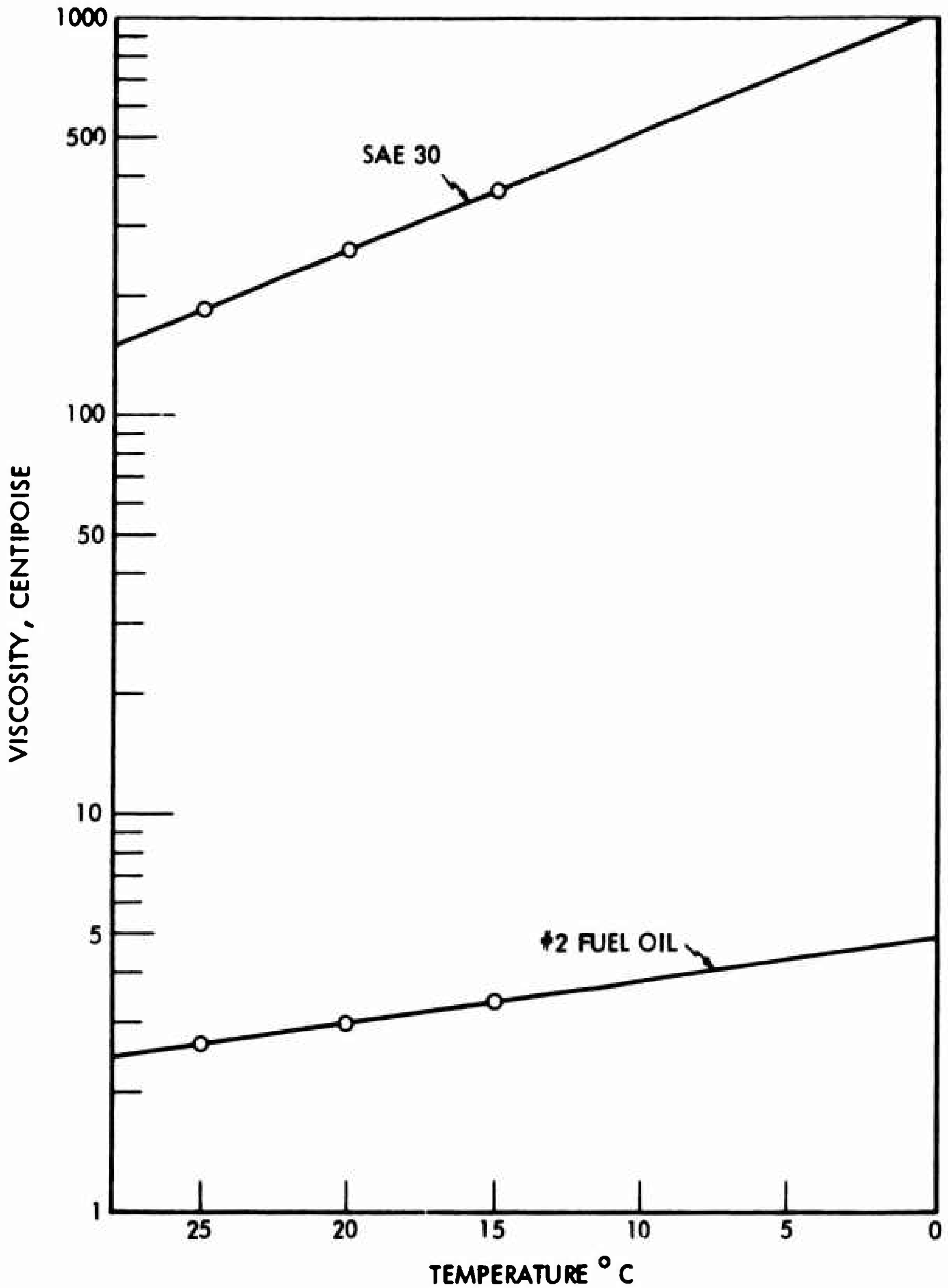


FIGURE 6 - OIL VISCOSITY

at the leading and trailing edges of the first baffle plate (between the plate and the clear sidewall). The forward dam was removed just as the carriage began accelerating. The aft dam remained in place to prevent oil from flowing to the other channels via the common area just ahead of the collection box.

The preload tests were run into clear water. The main advantage of this type of test is that a relatively clear view of the oil behavior within channel No. 1 is afforded. The free surface within the channel is made visable by the dark oil and the oil layer here cannot be confused with an oil slick between the model and the tank wall.

Thin Slick Tests - Tests in thin slicks are more representative of the device in its intended mode of operation. Two thicknesses were used: 0.04 and 0.12-in. The major difficulty with this type of test is that the flow is not steady in that the encountered oil collects in the aft end of the device and thickens during the run. The oil collection box was used in some tests to approach steady state by providing a reservoir for the collected oil and hence decreasing the accumulation of oil in the retarder channels.

When holes in the face of the collecting box were opened, oil would flow into the box and displace the water. Alternatively, holes in both the face and bottom were opened and water could flow through the box, whereas oil tended to be entrapped. The quantity of collected oil was not measured.

Several variables were investigated in the oil-skimming tests. Oil type, slick thickness, ard collecting-box conditions have already been mentioned. Two plate spacings, 1/4- and 17/32-in. were used over a range of carriage speeds from 1.0 to

10.5 fps. Plate immersion depth and trim were also varied, but not extensively. Most tests were run with a mean calm water immersion of 4-in. For these tests the trim was either level or with the bow and stern at 3-in. and 5-in. immersion depth, respectively.

Observations were made during a test run regarding droplet formation and, ultimately, the entrainment or leakage of oil droplets beneath the device. Observers tried to identify the mechanism of failure, when it occurred, and assessed the loss rate qualitatively as light, heavy, etc.

Most tests entailed several runs with identical conditions to enable the observers to refine their assessment of the flow characteristics. Of these runs, one was dedicated to obtaining still photographs at a fixed station near mid-length of the towing tank. The 35-mm slides, most in color, were viewed later to determine oil thickness and distribution in the first channel and to confirm or reassess the earlier observations.

DISCUSSION OF RESULTS

Velocity Distribution

Details of the velocity distribution test variables are listed in the Appendix. Total head measurements were only made with the 1/4-inch baffle spacing.

Head Measurements - Typical total-head measurements are shown in Figure 7. The longitudinal coordinate, x, is measured from the leading edge of the baffle plates. A separate plot is given for each of four test velocities. The data points are the average of readings at 1/2-in. and 2-in. probe immersion. Plate immersion was 3-in. Two symbols are used to differentiate between two test series (of March 11, 1974) for which only the

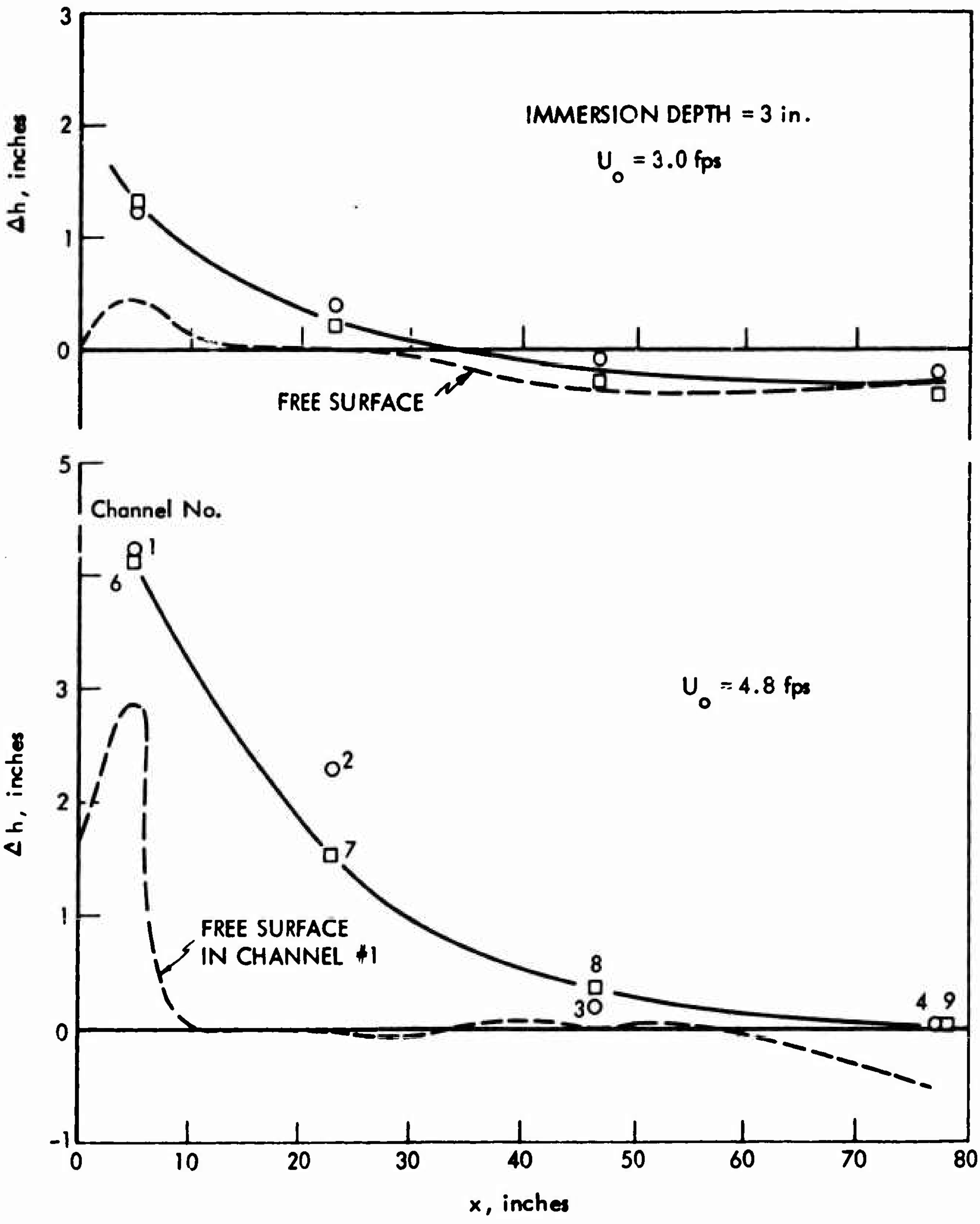


FIGURE 7 - TOTAL HEAD MEASUREMENTS

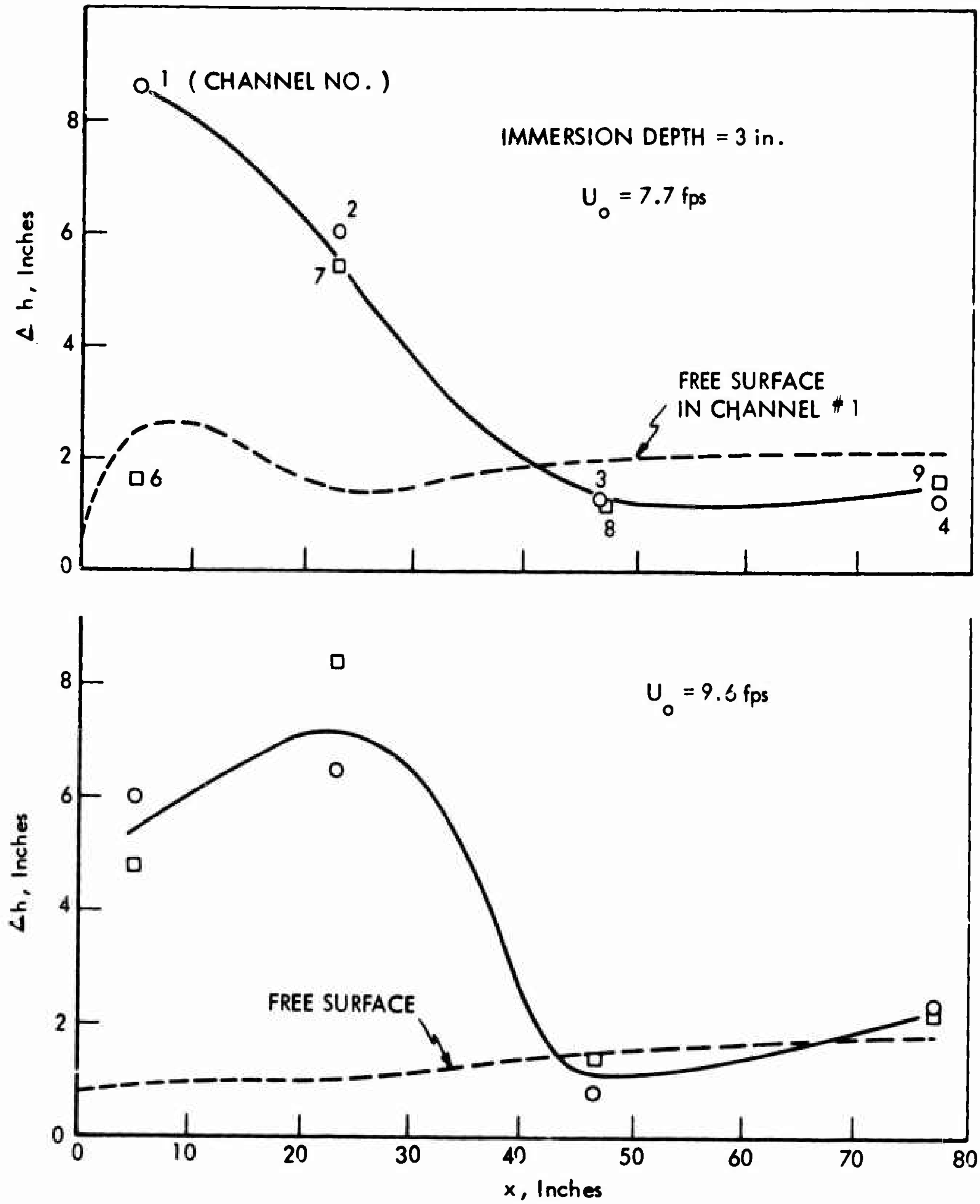


FIGURE 7 - CONCLUDED

lateral location of the probes was changed. Each data point is labeled by the channel in which each pair of probes was located (there were 14 channels numbered sequentially with No. 1 representing the one between the acrylic sidewall and the first baffle plate).

These data indicate that there are no systematic differences in head attributable to channel location. Data from the two series are generally in good agreement. The greatest discrepancy is at the first station (x = 5 in.) with U_o = 7.7 fps. We suspect that the inordinately low reading for the probes in channel 6 at this speed may have been caused by the probes not being centered in the channel, and yet, the readings at other speeds were comparable to those obtained in channel 1. The probes were modified prior to the March 13 tests to insure that they remain centered in the channel.

The conditions of Tests 1-4 were repeated in Tests 16-19 except that the probe immersions were 1" and 2" instead of $\frac{1}{2}$" and 2". The readings from these tests are included in Table 1 along with the data from Tests 5-8 (wherein probes were located in channels 6-9). Each entry in the table is actually the average of the reading made by observers during the tests and the reading taken later from photographic records.

Inspection of Table 1 leads us to conclude that the flow is one-dimensional, that is, the velocity field within the module is a function of the longitudinal parameter (x), but is practically independent of the immersion depth (y) and the lateral location or channel number.

Total head readings with larger plate immersion depths are listed in Table 2. These data confirm that the velocity field is nearly uniform across a vertical cut. Furthermore, the head at a given station is, at sufficiently low speeds, independent

TABLE 1

Summary of Total Head Readings
at 3-in. Immersion Depth

	Probe Depth y, in.	Channel No.	U_o, fps 3.0	4.8	7.7	9.6
			x = 5 in.			
Tests 5-8	0.5	6	1.4	4.2	2.9	4.7
	2.0	6	1.3	4.1	0.6	5.2
Tests 1-4	0.5	1	1.2	4.2	8.8	6.1
	2.0	1	1.3	4.3	8.5	6.0
Tests 16-19	1.0	1	0.9	2.8	7.6	11.0
	2.0	1	0.8	2.9	5.0	8.9
			x = 23 in.			
	0.5	7	0.1	1.4	5.6	8.5
	2.0	↓	0.3	1.6	5.2	8.4
	0.5	2	0.4	3.0	6.5	7.5
	2.0		0.4	1.6	5.7	5.5
	1.0		0.2	1.5	3.6	4.6
	2.0	↓	0.2	1.2	2.8	3.5
			x = 47 in.			
	0.5	8	-0.4	0.3	1.1	1.3
	2.0	↓	-0.2	0.4	1.4	1.5
	0.5	3	-0.1	0.1	1.1	0.8
	2.0		0.1	0.2	1.4	0.8
	1.0		0.1	0.1	1.3	0.9
	2.0	↓	0.1	0.2	1.5	1.4
			x = 77 in.			
	0.5	9	-0.4	0.2	1.3	1.6
	7.0	↓	-0.4	-0.1	1.9	2.6
	0.5	4	-0.2	0	1.0	1.8
	2.0		-0.2	0	1.5	2.7
	1.0		-0.2	-0.4	1.4	1.2
	2.0	↓	-0.2	-0.3	2.0	2.0

TABLE 2

Total Head Readings at
6-in. and 9-in. Immersion Depth

	Probe Depth y, in.	U_o, fps 3.0	3.9	4.8
	x = 5 in.			
Tests 11, 12 (9-in. depth)	1.0	1.1	2.2	
	6.0	1.2	2.0	
Tests 13, 14 (6-in. depth)	1.0	1.0		3.6
	5.0	0.9		3.2
	x = 23 in.			
	1.0	-0.1	-0.1	
	6.0	-0.2	0.9	
	1.0	0.2		1.6
	5.0	0.2		1.8
	x = 47 in.			
	1.0	-0.3	-0.3	
	6.0	-0.2	0.0	
	1.0	-0.3		0.0
	5.0	-0.2		0.3
	x = 77 in.			
	1.0	-0.3	-0.5	
	6.0	-0.2	-0.6	
	1.0	-0.4		-0.5
	5.0	-0.5		-0.4

of the plate immersion depth. At the larger plate depths, a critical velocity was reached above which a breaking wave was formed ahead of the baffle plates. No measurements were made under these conditions. It is clear, however, that the longitudinal velocity distribution is greatly changed by the breaking wave.

Free Surface Correction - The total head change in the manometers is the sum of the dynamic (or velocity) head plus any change in static head at the probe tip. The change in static head may be approximated by the change in free surface level over the probe. Profiles of the free surface (with respect to the undisturbed level) were obtained from Test No's. 5-8. Photographic records were viewed to determine the free surface level in channel No. 1. The free surface inside the channel generally lies above the level outside the model just behind the leading edge of the baffle plates. Thereafter, the level inside lies slightly below the level outside.

The free surface profiles are a function of velocity. They are represented in Figure 7 by the dashed lines (readings were only taken at the probe stations). It may be noted that the negative head readings recorded for stations III and IV at U_o = 3.0 fps seem to correlate with the local depression in free surface. On the other hand, at U_o = 7.7 fps, the total head reading lies below the free surface at these two stations. This unusual result indicates that pressure gradients, in addition to hydrostatics, must exist in the flow.

Comparison with Theoretical Prediction - Average values of the head readings in Table 1 for each combination of speed and station are presented as data points in normalized form in Figure 8. The longitudinal station, x, is normalized by the baffle

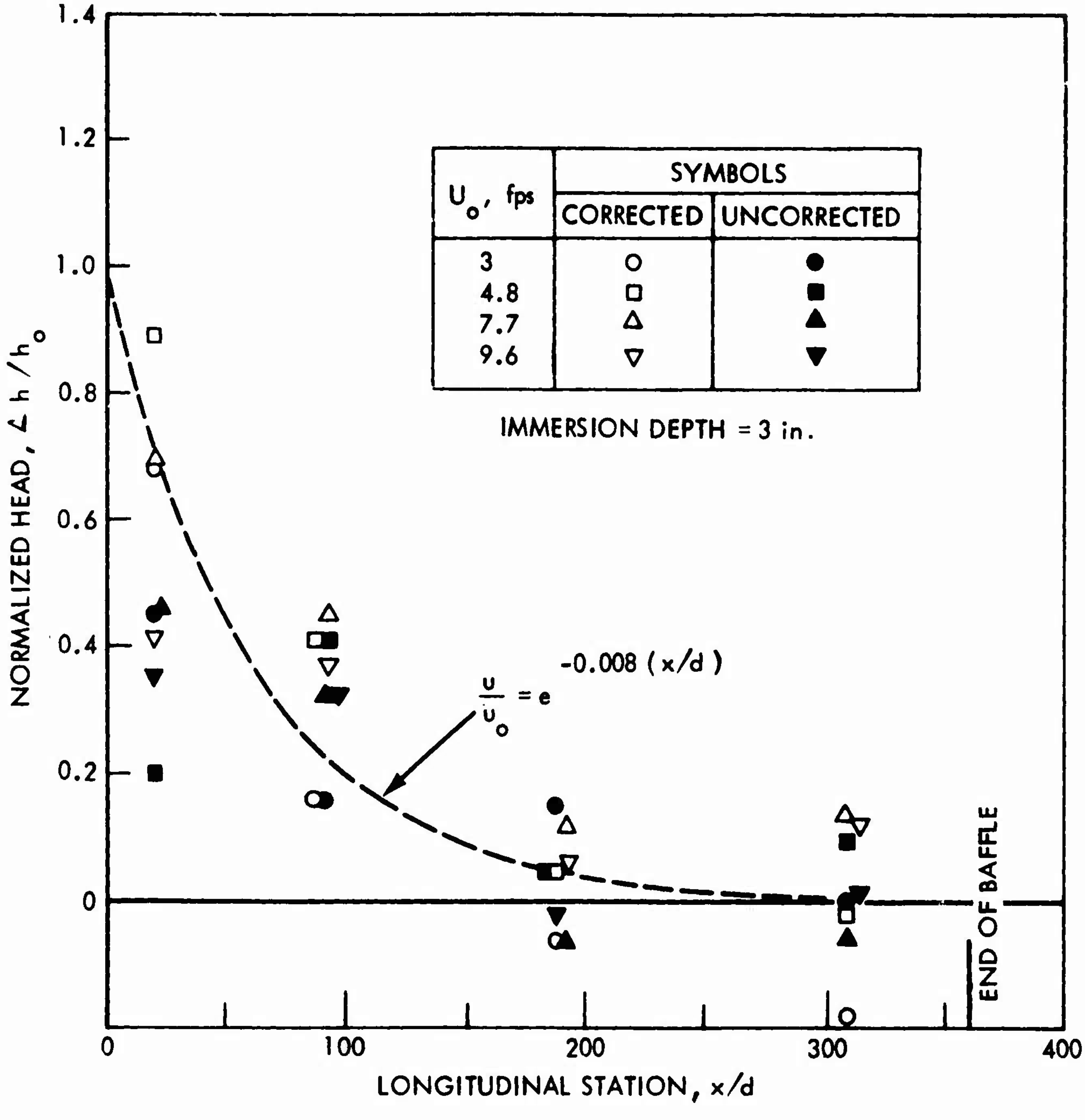


FIGURE 8 - NORMALIZED VELOCITY ATTENUATION

spacing, d. The head is normalized by the dynamic head associated with the carriage velocity,

$$h_o = 12\ U_o^2/2g\ ,\ \text{in.} \qquad [1]$$

Both uncorrected and corrected values are shown for comparison. The corrected values were obtained by first subtracting the change in free surface (Figure 7) from the corresponding averaged change in head.

A simplified theory for the velocity distribution in the retarder is predicted on the assumption that viscous forces predominate the flow. The resulting prediction is that

$$\frac{u}{U_o} = e^{-f(x/d)}\ , \qquad [2]$$

where u is the mean velocity in the channel measured relative to the model, U_o is the free stream velocity and f is a friction factor. For the present case, smooth plates, we expect the friction factor to be low, $\approx$ 0.008. This theoretical model is represented by the dashed line in Figure 8. Note,

$$\frac{\Delta h}{h_o} = \left(\frac{u}{U_o}\right)^2\ . \qquad [3]$$

The observed deviations of the corrected data from the predicted curve are caused largely by the fact that dynamic effects, made manifest by the observed wave inside tne model behind the leading edge of the baffle plates, were neglected in the simple theory. Expansion of the streamlines in the "leading edge" wave would, naturally, produce lower velocities here (by continuity). Further downstream the potential energy

(head) in the wave crest is reverted to kinetic energy. However, in the meantime, the energy dissipation rate is lower than predicted because of the lower local velocity. Thus, at Station II ($x/d = 90$) the velocity may be higher than predicted by the simple model.

Oil Skimming Characteristics

The basic principal of the SVROS is that it gradually absorbs kinetic energy in the surface fluid layers, the oil slick and an underlying region of water, so that high velocity oil flowing into the skimmer transmutes, unperturbed, to a relatively stagnant pool without entrainment of oil droplets into the water layer. "Entrainment failure" is now recognized as a critical mechanism which usually limits the control and recovery (by whatever means) of oil slicks to low current. Simple oil retention barriers (booms) fail in this regard at currents above approximately one-knot simply because excessive energy gives rise to large interfacial shear stresses and attendant droplet production.

The SVROS model utilized in this test program can, under ideal conditions, recover an oil slick in currents exceeding 10 fps. With some changes to these conditions, however, entrainment losses may be induced at speeds as low as 1.0 fps. In some cases the mechanism of failure appears to be identical to one or another failure mode commonly experienced with simple booms such as "headwave entrainment" or "near (boom) field" entrainment[3] On the other hand, details of the flow field inside the retarder channels cause novel failure mechanisms to appear in other cases.

The following discussion will identify the failure modes frequently experienced by the SVROS model, analyze effects of

the test variables and explore ways in which the present SVROS configuration might be changed to improve its performance. Details of test sequence, including observations, are presented in the Appendix.

Loss Mechanisms - With No. 2 Fuel Oil slicks and 1/4" baffle plate spacing (Tests 51-74), a frequent mode of entrainment loss was observed to be associated with the "leading edge" wave noted in the velocity distribution tests. This "internal wave" is generally the only region in which the free surface inside the model lies above the free surface outside the model. Typically, the oil slick inside the module is thickened at the back end and locally behind the point where the inside free surface falls below the free surface on the outside. This local area behind the wave is highly agitated, as if the flow was separated here. Naturally, the agitation produces oil droplets which, if driven deeply into the underlying water, are lost. These features are shown in Figure 9.

When the No. 2 oil was preloaded, i.e., no oil inflow, (Tests 21-50) accumulation was primarily in the back end and, typically, wedge shaped or roughly rectangular. (The "headwave" formation, a characteristic of free oil flows, was notably absent.) The predominant failure mode in the preload tests is like the "near field" type of entrainment observed for simple oil booms[3], wherein droplets are created by a local eddy above the stagnation streamline (that terminates on the boom face). The stagnation eddy is unsteady and entrainment occurs in irregular bursts. Droplets driven below the stagnation streamline are carried beneath the collection box by the downward flow around the box (or boom).

When the thickness of the oil pool at the collection box approaches the local depth of immersion, the entrainment rate is

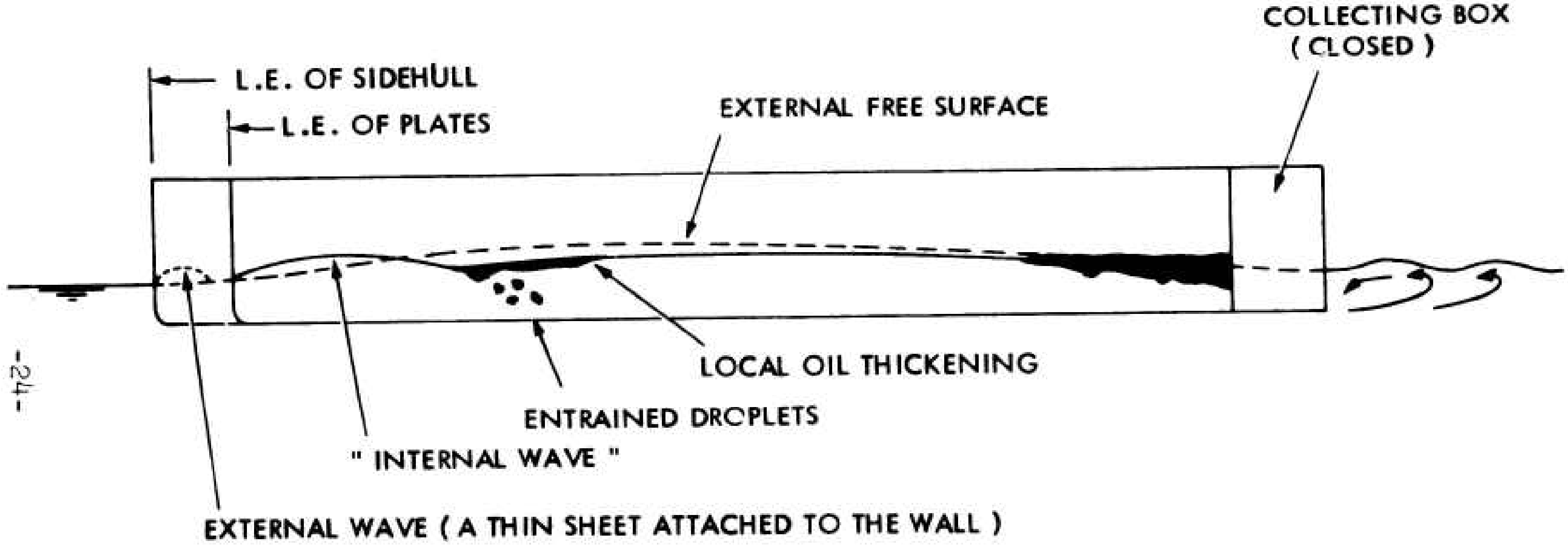


FIGURE 9 - SKETCH OF SKIMMER COLLECTING A THIN NO. 2 FUEL OIL SLICK SHOWING SALIENT FEATURES OF FLOW (NOT TO SCALE)

increased to where we describe the failure mode as "drainage/ entrainment" (Tests 50 and 123). (Simple drainage of oil beneath a boom only occurs in low currents with shallow draft barriers and/or high specific gravity oils.)

With 30 wt. motor oil slicks and 1/4" plate spacing (Tests 110-115) a thick oil "headwave" is formed behind the leading edge of the baffles, independently of the leading edge type of wave. Droplets are entrained behind the headwave and lost even at low speed. At higher speed the viscous oil entering the slots between the baffle plates creates a blockage which results in the formation of a breaking bow wave ahead of the plates with heavy entrainment and loss.

If the 30 wt. oil is preloaded (Tests 100-105), there is no headwave and no losses at low speed. In tests at intermediate speeds much of the viscous oil is "smeared" on the baffle plates when the free surface level inside the model rises at the beginning of the run. At the highest speed, the preloaded oil creates sufficient blockage to create a small breaking wave ahead of the plates.

The loss mechanisms mentioned above were all experienced with 1/4" baffle spacing. When the spacing is increased to 17/32" the primary mode for failure is quite different. At this spacing (Tests 120-150), the formation of internal waves was much reduced. Retardation of the underlying water was also reduced so that entrained droplets were formed all along the oil/ water interface with 30 wt. oil. With No. 2 Fuel Oil the losses generally originated from the region of greatest thickness and is some cases could be classified as "near field" entrainment.

Effect of Trim - The severity of the "leading edge" waves that occurred with 1/4" baffle spacing were successfully reduced

by trimming the model by the stern. The reduced depth of the bow decreases the blockage here, while the increased depth at the stern is favorable from the standpoint of reclaiming droplets that are formed along the interface since the depth that a drop must be driven (to be entrained) is greater.

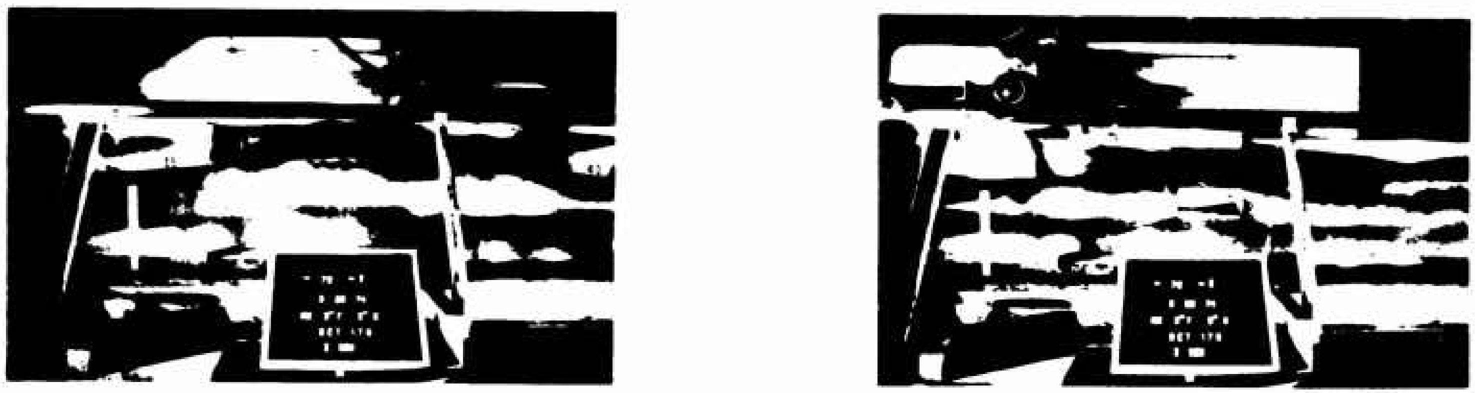
Figure 10 shows photographs of two test runs made with the model trimmed: 3" immersion at the bow and 5" immersion at the stern, in calm water. Two views are shown for each run, one of the bow and one of the stern end as they pass a station 43 feet from the starting end of the towing tank. In Test No. 65 light entrainment was noted from the (reduced) leading edge wave disturbance seen around x = 22". In Test No. 72 oil is thickened locally behind x = 10" without any entrainment. The main pool at the back end is much thicker, t = 2.5" at x = 80". The collection box was closed in these two tests.

It is interesting that Test No. 60 and 51 at 8.5 and 10.4 fps had no entrainment loss whereas Test No. 65 at 7.8 fps did have entrainment. This is explained by the change in the leading edge wave as a function of speed. At the highest speeds the leading edge wave either does not exist or is on the order of the model in length (note the free surface profile in Figure 7 for U_o = 9.6 fps compared with U_o = 7.7 fps).

Alternative approaches for reducing the leading edge wave, aside from trimming the SVROS, include: sweep back the leading edges of the baffle plates and stagger the leading edges to obtain a more gradual disturbance to the inflow.

The effect of trim was not as beneficial at the larger plate spacing, probably because the leading edge wave is not as pronounced at this spacing. Performance was slightly improved for No. 2 fuel but the 30 wt. oil slick was collected slightly more effectively with zero trim.

a. Test No. 65, U_o = 7.8 fps, t_o = 1 mm (0.04 in.)



b. Test No. 72, U_o = 6.3 fps. t_o = 3 mm (0.12 in.)

FIGURE 10 - TEST RUNS WITH NO. 2 FUEL OIL SLICKS AND MODEL TRIM

Effect of Viscosity - Oil viscosity has a profound effect on the slick behavior in the SVROS as witnessed by the formation of a breaking bow wave when the 1/4" passages became "clogged" with 30 wt. at oil (Tests 110-115). It is clear that the rate of retardation was excessive for the more viscous oil slick. On the other hand, at the 17/32" spacing retardation of 30 wt. oil may have been about right whereas the underlying water was not slowed sufficiently. The energy absorption was not adequate for the No. 2 fuel slicks at this plate spacing.

Some means of maintaining the proper energy dissipation rate(s) for a wide range of oil viscosities needs to be found. One approach would utilize rough plates for which low viscosity fluids would be in turbulent flow and high viscosity fluids would remain laminar. In this manner the friction coefficient for a viscous oil would not differ greatly from the friction for the underlying water.

Another scheme would involve an SVROS configuration with one plate spacing at the free surface (for viscous oil) and a decreased spacing below (for water). To adjust for low viscosity oil, the configuration would be raised so that the decreased spacing starts above the free surface.

Effect of Slick Thickness - The performance of the SVROS seems to be degraded somewhat by increasing the thickness of the oil encountered. Even so, collection at slower speeds (to avoid entrainment losses) may still result in high collection rates compared to higher speed skimming of thinner slicks.

Effect of Collection Box - Flow of oil and water into and/or through the collecting box had some minor effects on entrainment losses. Generally, opening the box (front and bottom holes) worsened "near field" entrainment but allayed losses originating

further upstream. The oil trapped in the collection box was often highly agitated (by the water flowing through).

The collection box may prove superfluous if oil can be withdrawn satisfactorily from the thickened pool at the back end of the baffle plates.

CONCLUSIONS

The present model configuration of the SVROS can collect oil without losses in currents greater than 10 fps (Test 61), in a 1-mm slick of No. 2 Fuel Oil. A thicker slick, $t_o = 3$ mm induces entrainment losses at a speed between 6.3 and 7.8 fps. More viscous (250 cp) 30 wt. motor oil was collected at 4.0 fps (Test 147) without loss.

The skimming characteristics can be improved by: 1) controlling the formation of the leading edge wave inside the retarder and 2) matching the dissipation rates between the oil phase and water phase for more viscous slicks.

RECOMMENDATIONS

The feasibility of the SVROS concept for the control of oil slicks at high current velocity has been demonstrated. The present SVROS model has collected thin (0.04 in.) slicks of No. 2 Fuel Oil and 30 wt. motor oil up to speeds of 10.4 and 4.0 fps, respectively, with no loss of oil. But, more important than this achievement, the present test program has enabled us to identify features of the flow which are critical under certain conditions in that they lead to droplet formation and subsequent entrainment loss. With this knowledge, we are in a position to pursue refinements to the basic retarder configuration that will, we are confident, greatly improve the SVROS' performance characteristics. Hence, we recommend that a program of retarder optimization be undertaken.

APPENDIX

TEST LOG

TEST DESCRIPTION Velocity Distribution **DATE** 03/11/74

Baffle spacing 1/4 **in.**
Immersion depth 3 **in.**
Water temp. 12.5 **°C**
Oil type ______

<table>
<tr><th>Test No.</th><th>Velocity, fps</th><th>Remarks</th></tr>
<tr><td>1
2
3</td><td>3.0
4.8
7.7</td><td>Probe Locations:
<table><tr><td>Station, X, in.</td><td>5</td><td>23</td><td>45</td><td>77</td></tr><tr><td>Channel No.</td><td>1</td><td>2</td><td>3</td><td>4</td></tr></table>Y = 0.5 and 2.0 in.</td></tr>
<tr><td>5
6
7
8</td><td>3.0
4.8
7.7
9.6</td><td>Probe Locations:
<table><tr><td>Station, X, in.</td><td>5</td><td>23</td><td>47</td><td>77</td></tr><tr><td>Channel No.</td><td>6</td><td>7</td><td>8</td><td>9</td></tr></table>Y = 0.5 and 2.0 in.</td></tr>
</table>

TEST DESCRIPTION Velocity Distribution DATE 03/13/74

Baffle spacing 1/4 in.
Immersion depth 9 in.
Water temp. 15 °C
Oil type

Test No.	Velocity, fps	Remarks
11	3.0	Locations as for tests 1 - 4 but with
12	3.9	Y = 1.0 and 6.0 in.
13	3.0	Changed Immersion Depth to 6 in. with
14	4.8	Y - 1.0 and 5.0 in.
15	7.7	Breaking Wave no data
16	3.0	Changed Immersion Depth to 3 in. with
17	4.8	Y = 1.0 and 2.0 in.
18	7.7	
19	9.6	

TEST DESCRIPTION Oil Preload **DATE** 03/15/74

Baffle spacing 1/4 in.
Immersion depth 6 in.
Water temp. 15 °C
Oil type No. 2 F.O.

Test No.	Velocity, fps	Remarks
		100 cc in Channel No. 1
21	3.0	t = 1.4", droplets formed, but no loss
22	4.8	t = 2.3" at X - 83", pool is unsteady
		200 cc in Channel No. 1
23	3.0	t - 1.9", no loss of droplets
24	4.8	t = 3.5", wedge 22" long, some drainage
25	6.1	light loss from back of pool
		Changed Immersion Depth to 4 in.
		100 cc in Channel No. 1
26	3.0	Similar to Test 21
27	4.8	intermittent entrainment, t = 2"
28	7.7	t = 2", pool 12" long, light entrainment
29	9.6	no entrainment?
		200 cc in Channel No. 1
30	3.0	t = 1.7", pool ≈ 60" long, light entrainment
31	2.0	t = 1.5", droplets formed but no loss
32	4.8	t = 2.3", intermittent drainage
33	7.7	t = 3.5", 10" long pool, light entrainment
34	9.6	light entrainment and intermittent drainage
		Changed Trim: 2.0" at bow; 4.8" at stern
41	3.0	t = 2" at X - 75", lighter loss than Test 30
		100 cc in Channel No. 1
42	3.0	no loss
43	3.0	t = 2.5", 15" long pool, light periodic entrainment
44	7.7	t = 2.0", very light entrainment
45	9.6	little or no loss

TEST DESCRIPTION Oil Preload DATE 03/18/74

Baffle spacing $\frac{1}{4}$ in.
Immersion depth 2.0 in. at bow, 4.8 in. at stern
Water temp. 15 °C
Oil type No. 2 F.O.

Test No.	Velocity, fps	Remarks
		100 cc in Channel No. 1
46	3.0	Same as Test 41
47	5.4	t = 1.2", pool 28" long and well behaved
48	7.7	t = 1.5", 7.5" immersion at stern, no loss
49	9.4	surface highly agitated, oil smeared on plates
		200 cc in Channel No. 1
50	9.4	Moderate drainage/entrainment

TEST DESCRIPTION Oil Slick DATE 03/20/74

Baffle spacing 1/4 in.
Immersion depth 4.5 in.
Water temp. 15 °C
Oil type No. 2 F.O. - 1 mm thick

Test No.	Velocity, fps	Remarks
		Collection Box holes: all open in front, one row open in bottom
51	4.0	t = 0.8 at back, local pool at X = 15
52	3.1	t = 0.7
53	4.9	t = 1.0, pool 15" long and extends into Box
54	7.8	agitation at X = 20" causes light entrainment
		All bottom holes opened
55	7.8	incipient loss from X = 85", none from X - 20"
56	9.8	light entrainment from X = 24", oil in Box agitated
		All holes in collection box closed
57	8.5	agitated at X = 20" with some loss
		Changed Immersion Depth to 4.0 in.
58	8.5	Same as Test 57
		Changed Trim: 3" at bow, 5" at stern
60	8.5	much less agitation than Test 57, no loss
61	10.4	disturbance at X = 30", no loss!
62	3.1	
63	4.0	t = 1.0"
64	6.3	t = 1" by 16" long pool at back
65	7.8	light entrainment from X = 22"

TEST DESCRIPTION Oil Slick DATE 03/20/74

Baffle spacing 1/4 in.
Immersion depth 3 in. at bow, 5 in. at stern
Water temp. 15 °C
Oil type No. 2 F.O. - 3mm slick

Test No.	Velocity, fps	Remarks
		Collection Box Closed
70	3.1	t = 2", headwave at X = 20", light entrain.
71	4.0	headwave less pronounced, no loss
72	6.3	local pool behind X = 10", t = 2.5" @ X=80"
73	7.8	t = 4" at X = 30" with light entrainment
74	10.4	similar to Test 73.

TEST DESCRIPTION Oil Preload DATE 03/21/74

Baffle spacing 1/4 in.
Immersion depth 3 in. at bow, 5 in. at stern
Water temp. 15 °C
Oil type 30 wt.

Test No.	Velocity, fps	Remarks
		100 cc in Channel No. 1
100	3.1	t = 1.5", oil in wedge from X = 60" to 90"
101	4.0	t = 1.7" at X = 90", wedge begins at X = 60"
102	4.9	t = 1.8"
103	6.3	Droplets formed at X = 65", no loss, t ≈ 1"
104	7.8	Most oil is "smeared" on plates from f.s.change
105	10.4	Breaking wave, light loss

TEST DESCRIPTION Oil Slick DATE 03/21/74

Baffle spacing $\frac{1}{4}$ in.
Immersion depth 3 in. at bow, 5 in. at stern
Water temp. 15 °C
Oil type 30 wt. - 1 mm slick

Test No.	Velocity, fps	Remarks
		Collection Box Closed
110	3.1	3"headwave begins at X = 1", heavy entrain.
111	4.0	as above
112	4.9	headwave begins at X = 26", heavy entrain.
113	6.3	9" immersion at X = 18", heavy entrainment
114	7.8	Breaking bow wave
115	10.4	Breaking wave

TEST DESCRIPTION Oil Preload DATE 03/28/74

Baffle spacing 17/32 in.
Immersion depth 3 in. at bow, 5 in. at stern
Water temp. 15 °C
Oil type 30 wt.

Test No.	Velocity, fps	Remarks
		400 cc in Channel No. 1
120	3.1	droplets form along interface
121	5.2	light entrainment
122	7.8	moderate entrainment near back end
123	10.4	drainage/entrainment, heavy loss

TEST DESCRIPTION Oil Slick **DATE** 04/23/74

Baffle spacing 17/32 **in.**
Immersion depth 4 **in.**
Water temp. 20.5 **°C**
Oil type No. 2 F.O. - 1 mm slick

Test No.	Velocity, fps	Remarks
		Collecting Box Closed
131	3.1	t = 1.5" @ X = 80" with inception
132	5.2	t = 1.2' @ X = 86", moderate loss
133	7.0	Heavy entrainment, loss ~ encounter
134	9.5	Free surface agitated, no retention
		Opened all Collecting Box Holes
135	5.2	Similar to Test 132, oil in Box is agitated
		Changed Trim: 3.2" at bow, 5.5 at stern
136	5.2	Better than Test 135, light entrainment
137	3.1	Similar to Test 131, incipient loss
Added oil to 3 mm thickness		
138	3.1	t = 2.5" @ X = 82", 2" in Box, incipient loss
139	5.2	t = 2" in Box, moderate loss
		Closed Collecting Box
141	5.2	t = 2.8" @ X = 82", moderate loss
142	3.1	t = 3.1" @ X = 81", incipient loss

TEST DESCRIPTION Oil Slick DATE 04/23/74

Baffle spacing 17/32 in.
Immersion depth 3.2 in. at bow, 5.5 in. at stern
Water temp. 20.5 °C
Oil type 30 wt. - 1 mm slick

Test No.	Velocity, fps	Remarks
		Collecting Box Closed
143	3.1	Droplets form at X = 30" but no loss
144	5.2	Droplets all along interface, light loss
		Opened all holes in Box
145	5.2	Similar to Test 144, some collection in Box
146	4.0	t ≈1.5" in Box, incipient loss upstream
		Changed to zero trim and 4" immersion
147	4.0	t ≈ 1.0" in Box, droplets formed but no loss
148	5.2	light loss, oil in Box agitated
149	7.0	moderate loss
150	9.5	heavy loss

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